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Renewable and Sustainable Energy Reviews
11 (2007) 2032–2057

RENEWABLE & SUSTAINABLE ENERGY REVIEWS

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Forty candles for the Rance River TPP tides provide renewable and sustainable power generation

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Received 27 February 2006; accepted 24 March 2006

Abstract

Prices of oil and other fossil fuels have proven a powerful incentive for the alternative energy hunters. The alternatives include the various forms of ocean energy that, often considered uneconomical for electricity generation, have become attractive and competitive. Many sites throughout the world have been considered, at one time or another, suitable for implantation of a tidal power station, but very few have witnessed implementation of often ambitious plans. The Rance River tidal power plant, near St Malo in Brittany (France) is an exception. It is celebrating in 2006, 40 years of durable, loyal and productive service.

Keywords: Bulb turbines; Canada; China; Rance river; Russia; Tidal current; Tide mills

Contents

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1364-0321/$ - see front matter © 2006 Published by Elsevier Ltd.
doi:10.1016/j.rser.2006.03.015

1. Introduction

The price rise of traditional fuels, and particulalry oil and gas, and the concern for global warming, have been strong incentives for a renewed look at alternative sources of energy. Though only a modest potential contributor to alleviation of the 'crisis', attention has nevertheless been again directed toward ocean-generated power (Tables 1 and 3). A major anniversary is coming up for the largest tidal power plant currently (2006) in existence.

Publications dealing with turning the tidal energy into power spread over the better part of the 20th century; we could venture to say, without erring, even *ad libitum*. Among the more recent ones focusing on detailed examination of the basics, the principles and the economics are the contributions of Baker, Charlier and Gibrat.[1]

The economics have changed since the 1960s' and 1980s' books by these authors. Many other authors, of course, significantly added to the basic knowledge of tides and tidal power.[2]

Even some exquisite blueprints are to be found in the rather recently translated and published *Notebooks* of Leonardo da Vinci, and in the writings of Mariano.[3] The literature addressing specifically the Rance River tidal power plant is far less abundant, but far from negligible.[4]

[1]Baker, G.C., Tidal power. Some historical implications. *Proceedings of the Conference on New Approaches to tidal power. Bedford Inst.Ocean.* 1982, I, 1–6; Baker, G.C., *Tidal power.* London, Plenum Press 1982; Charlier, R.H., *Tidal energy.* New York, Van Nostrand-Rheinhold, 1982; Charlier, R.H. and Justus, J.R., Is tidal power coming of age? In Charlier, R.H. & Justus, J.R., *Ocean energies.* Amsterdam, Elsevier 1993 [Chapter 7]; Charlier, R.H., Sustainable co-generation from the tides. *Ren. Sust. Energy Rev.* 2003, 7, 3, 187–213; Gibrat, R., *Les usines marémotrices.* [in French: tidal power plants] Paris, Electricité de France 1955.

[2]Charlier, R.H., Sustainable co-generation from the tides. *Ren. Sust. Energy Rev. A bibliography,* 2003, 7, 3, 215–247.

[3]Richter, J.P., *The notebooks of Leonardo da Vinci.* New York, Dover 1970 [English translation]; Mariano, *Potentiae ædus usus* [in Latin: Utilization of the power of the tide]. Siena (anno 1438).

[4]*E.g.*, Gibrat, R., The first tidal power station in the world under construction by French industry on the Rance River. *French Technical Bulletin* 1962, 2, 1–11; Gougenheim, A., The Rance tidal energy installation. *J. Inst. Navigation* 1967, XX, 3, 229–236; Jones, J.E., The Rance tidal power station. *Geography* 1967, 53, 11, 412–415; Kammerlocher, L., La station marémotrice expérimentale de St Malo. [in French: the experimental tidal power station of St Malo] *Rev. Gén. de l'Electr*. 1960, 69, 5, 237–261; Mauboussin, G., Construction de l'usine marémotrice de la Rance. Contribution des essais sur modèle réduit à la mise au point d'un mode d'exécution des travaux. [in French: Rance tidal power station construction. Contribution of trials on reduced scale model of the work execution mode]. *La Houille Blanche-Rev.Int. de l'Eau (4es Journées de l'Hydraulique*) 1957, 388–399.

Table 1
Renewable and sustainable coastal zone alternative energy

Energy/power alternatives from ocean sources
In use
• Winds • Waves • Tidal currents • Tides
Potential
• Ocean currents • Temperatures differentials • Biomass • Salinity differentials • Others

2. Ancestors and forerunners

Tapping the energy of the ocean's tide and of the river's tidal current to produce mechanical power is a practice that goes back centuries.[5] A conventional tide mill included sluices, a dam, and retaining basin if it was not a run-of-the-river type mill, and wheels proved to be quite sophisticated equipment for the times (Figs. 4(a–c) and 5(a–b)). Often a mill included buildings among which the house of the miller (Fig. 4(c)). Though dreamt about for more than a century, only 40 years ago was the first 'sizeable' plant to capture the energy and turn it into electrical power built and placed in service. Since then small plants have been providing power in Russia, Canada and China[6] (Figs. 1–7). The French plant has provided reliable, sustainable, highly useful power, besides several other regional and national advantages. Every 10 years or so an analysis of its performance has been published, the last one in 1997[7] (Fig. 8).

[5]Charlier, R.H. & Ménanteau, L., The saga of tide mills. *Ren. Sust. En. Rev.*, 1997, 1, 3, 271–207; Charlier, R.H., Chaineux, M-C.P. & Ménanteau, L., Rise and fall of the tide mill. In Morcos, S., Zhu, M., Charlier, R.H. *et al.* (Eds.) *Ocean sciences bridging the Millennium.* Paris, UNESCO & Qingdao, Ocean Press 2004, pp. 314–338.

[6]Bautier, A.-M., Les plus anciennes mentions des anciens moulins hydrauliques et de moulins à vent. *Bull. Philolog. & Hist.* 1960, 2, 590–592 [in French: the oldest mentions of the old hydraulic mills and of wind mills]; Charlier, R.H., *Tidal energy.* New York, London, Melbourne, Van Nostrand-Rheinhold, 1982; Charlier, R.H. & Justus, J.R., *Ocean Energies: Environmental, Economic and Technological Aspects of Alternative Power Sources.* Amsterdam, London, New York, Tokyo, Elsevier Science Publ., 1993 [Oceanography Series]; Charlier, R.H., Ocean alternative energy. The view from China: small is beautiful. *Ren. Sust. Energy Rev.* 2001, 3, 3, 7–15; Ch'in Hsu-Ts'ung, The building of the Shamen TPP. *Tien Chi-Ju Tung-Hsin* 1958, 9, 52–56; Zu-Tian, G., The development of tidal resources in China: the tidal power experimental station of Jiangxca and its Nr 1 and Nr 2 bi-directional tidal water turbine. In Krock, H.J. (Ed.) *Ocean energy recovery Proceedings of the International Conference ICOER* 1989. Amer. Soc. Civ. Eng., Ocean Energy Div. Pacific Int. Center for High Technology Research, University of Hawaii-Manoa, pp. 157–166.

[7]See fn 13, Barreau.

Fig. 1. Views of the Rance River tidal power plant at St Malo, France.

Putting tides to work for power production has been proposed through four major methods. The most common idea consists in the float method whereby the incoming tide would raise a floating mass that, as it falls back to its original position could do useful 'work'. In a second approach a rotating paddle wheel is mounted on a shaft and activated by both ebb and flood tides, with power transmitted by a shaft (Figs. 9 and 10).

The third system is already more sophisticated; its use has been suggested in contemporary schemes, a.o. by Gorlov of Northeastern University (Boston)[8] (Figs. 8 and 9). Air contained in a conduct of metal or concrete is compressed by the incoming tide. The compressed air can be called upon at any time and the system thus frees the plant from

[8]Gorlov, A.M., Some new conceptions in the approach to harnessing tidal energy. *Proceedings of the 2nd Miami International Conference On Alternative Energy Sources,* 1979, 1171–1195.

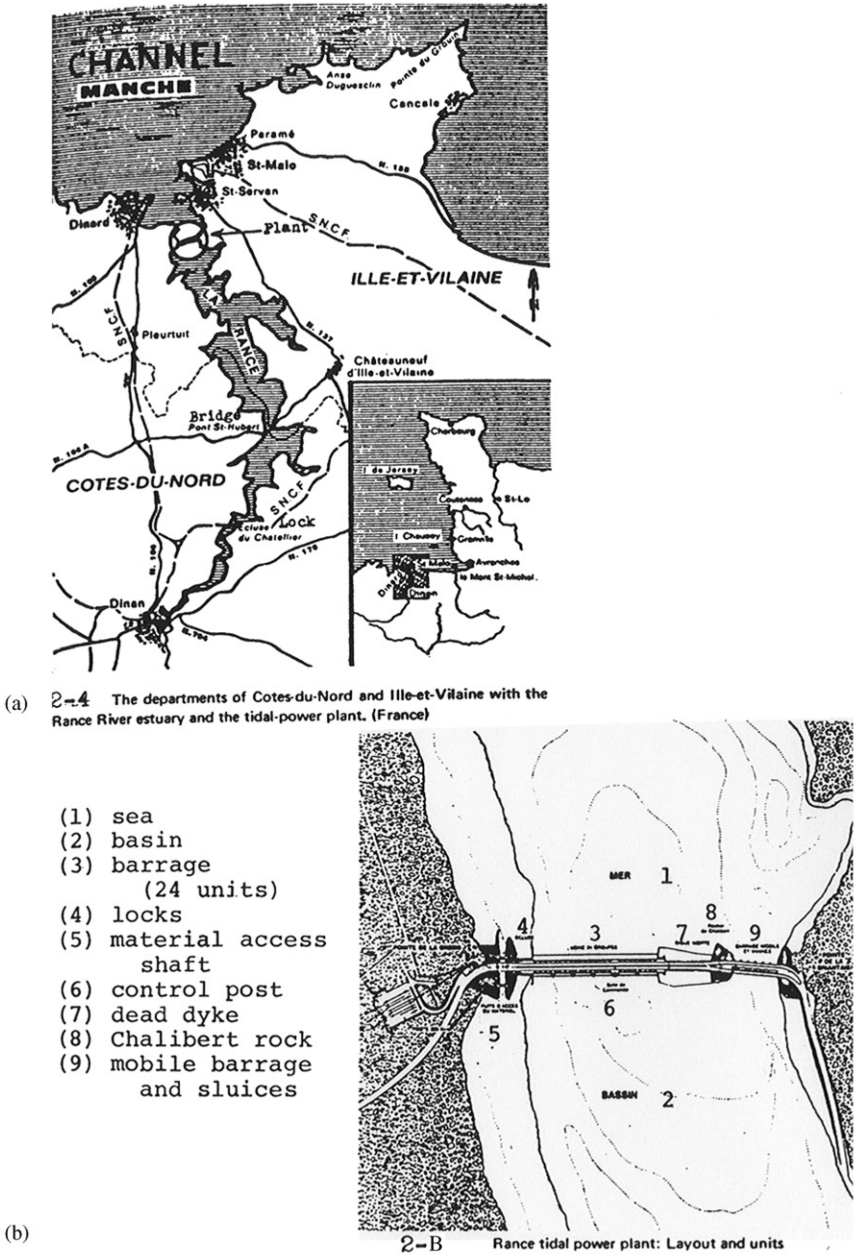


Fig. 2. (a) The departments of Côtes d'Armor (formerly Côtes du Nord) and Ile-et-Vilaine, the Rance River estuary and the tidal power plant. (b) Rance tidal power plant: layout and units.

the constraints of the lunar cycle. Gorlov has improved on his approach and publicized it in a seminar held at and organized by the university in 2005. And a fourth approach involves damming in part of the sea, providing a basin that fills up at incoming tide; the

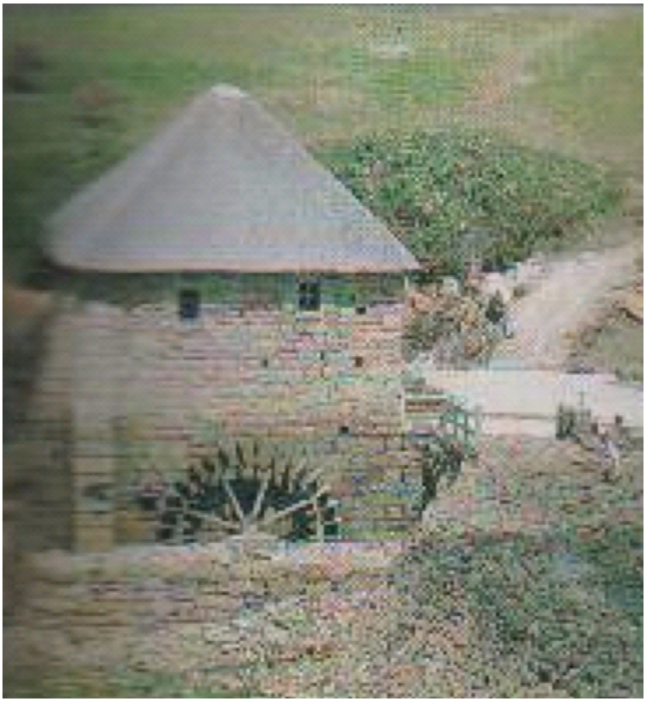


Fig. 3. Restored tide mill on the island of Bréhat (2005).

water is then released at low tide, forced to pass through turbines either back to the sea or, in multi-basins schemes, to another basin.

With oil prices having leaped up to levels reaching $80 a barrel, the interest for ocean energies has been rekindled. The cost of an ocean-generated kilowatt has become attractive. Even some thought is given to revive the tide mill, already a touristic attraction since several decades, and blossoming[9] (Fig. 11).

3. Tide mills bow out on the Rance

Half a century ago tide mills had not entirely disappeared from the power-producing scene. Some isolated ones were still in operation in the British Isles, on the Iberic Peninsula and in the French province of Brittany. Several worked, coincidentally, on the Rance River estuary (Fig. 12). The *abers* of Brittany had always been a privileged site for such water mills and the Aber Wrac'h had been the site of the ill-fated first attempt at constructing a tidal power plant in France.

The 'remnants of the past' were dismantled in 1960s to make room for a rather large electricity power plant generated by ocean energy. Their removal may, however, not be the last hurrah and there might perhaps be a modest renascence in the not so distant future.

[9]Tuttel, J., Watermolens, eeuwig oud en eeuwigblooeiend. *Aard en Kosmos,* 1978, 10, 8–9 [in Dutch: water mills, eons old and ever blossoming].

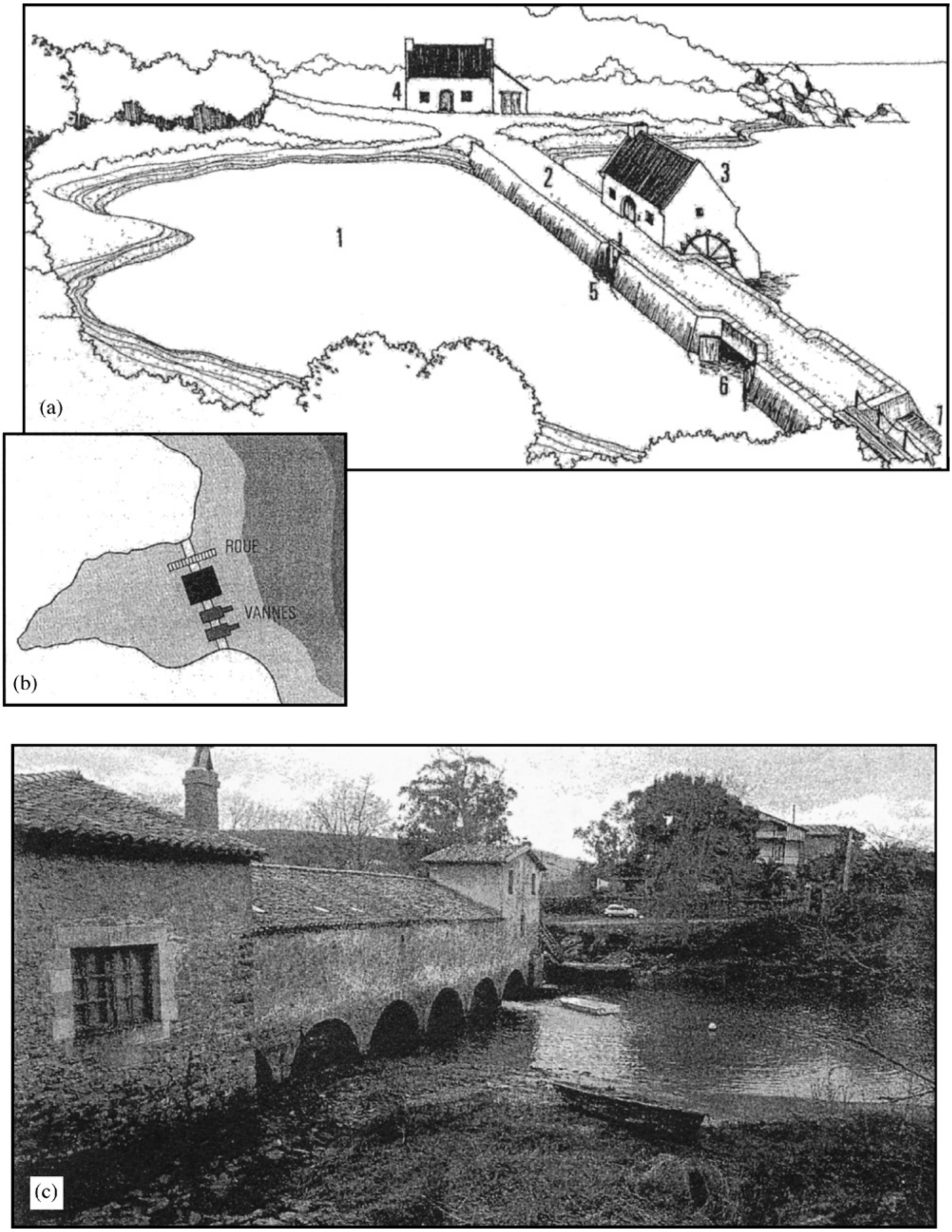


Fig. 4. (a) Drawing of a traditional tide mill and its surroundings: (1) pond, (2) causeway, (3) mill, (4) miller's dwelling, (5) exit sluice and hydraulic wheel, (6) entrance sluice gate, (7) bridge. (b) Simplified schematic representation of a traditional tide mill Roue = wheel; vannes = sluice gates. (c) Sea-facing façade of the mixed mill of La Venera (on the Rio de la Venera in Armoem, Cantabria) at low tide. The mill building, now a private residence, was restored in the late 1990s.

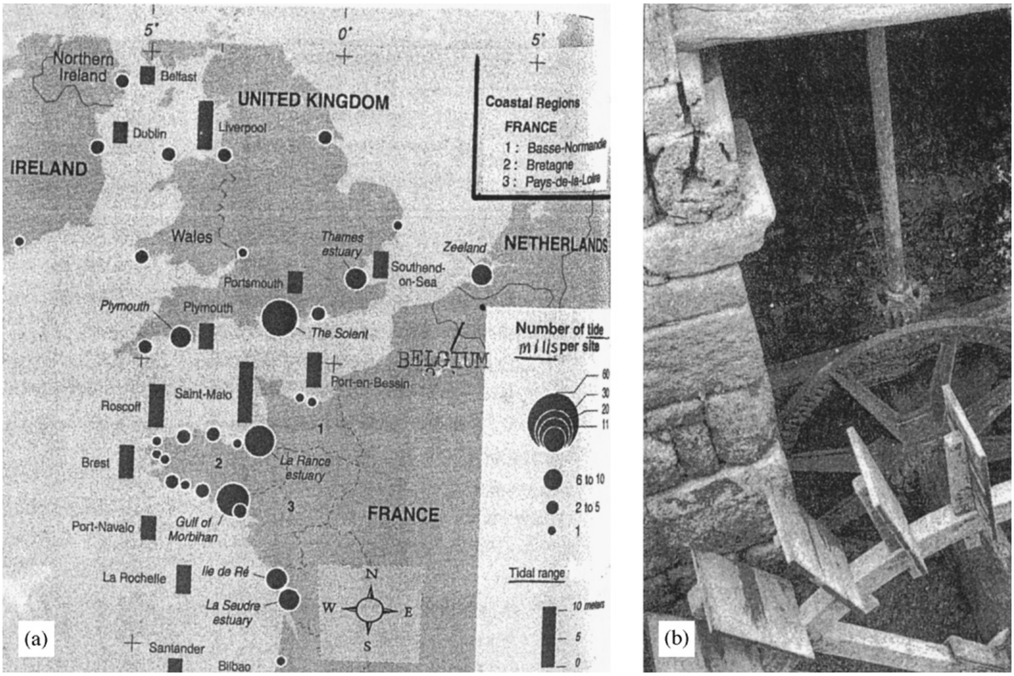


Fig. 5. (a) Pre-21st century locations of tide mills north of the Gironde River (France). No less than 20 tide mills were implanted on the Rance River estuary prior to construction of the Rance River TPP. (b) The hydraulic system of the Traou (France) mill: photograph shows paddle wheel.

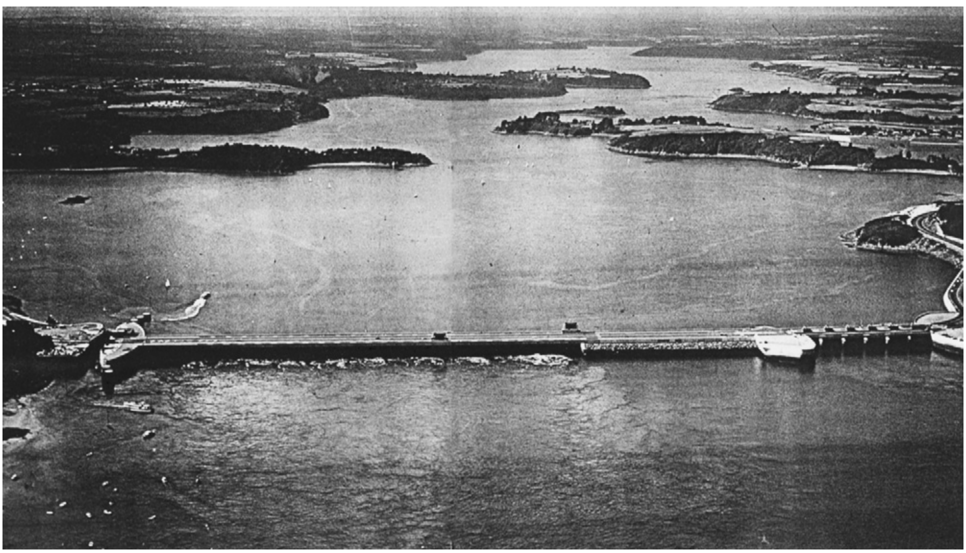


Fig. 6. Areal view of the Rance River TPP.

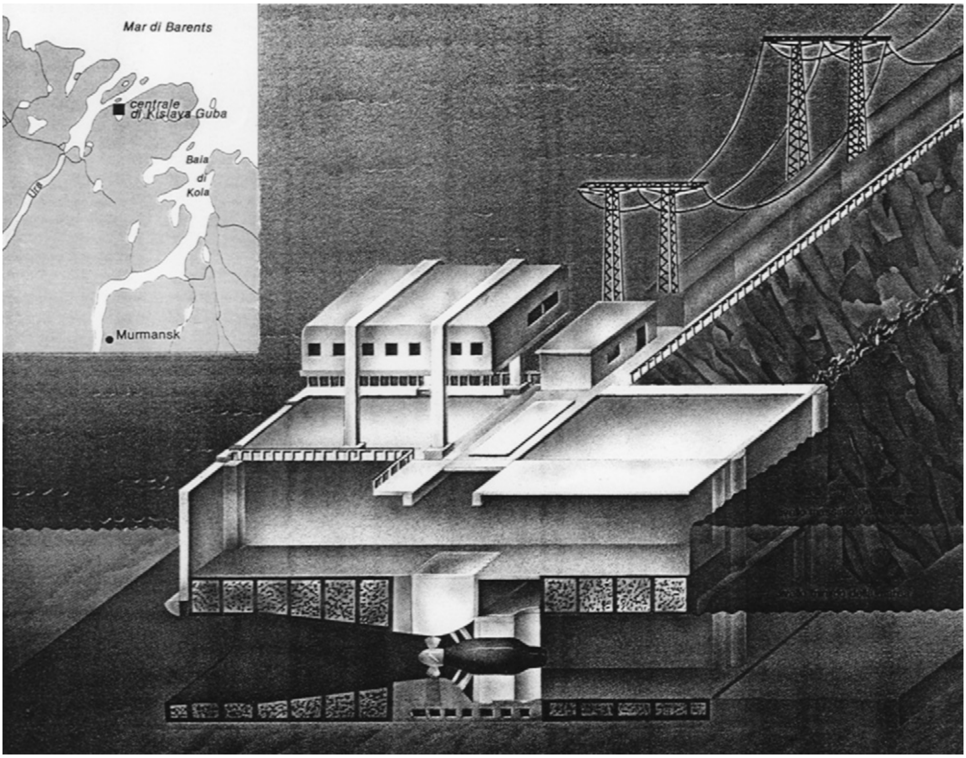


Fig. 7. Map of Murmansk, Russian Federation and drawing of Kislaya TPP.

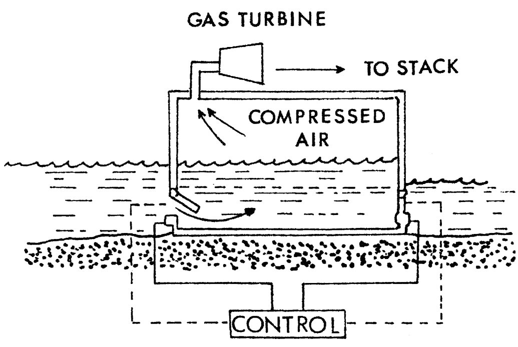


Fig. 8. Gorlov's system. Compressed air exits to shaft.

3.1. The Rance River plant

Three precise sites were eventually retained to locate a tidal power station (Fig. 13). The system chosen by the Rance River plant builders[10] is only one of four 'basic' ones. The first

[10]SOGREAH = Société Grenobloise d'Applications Hydrauliques.

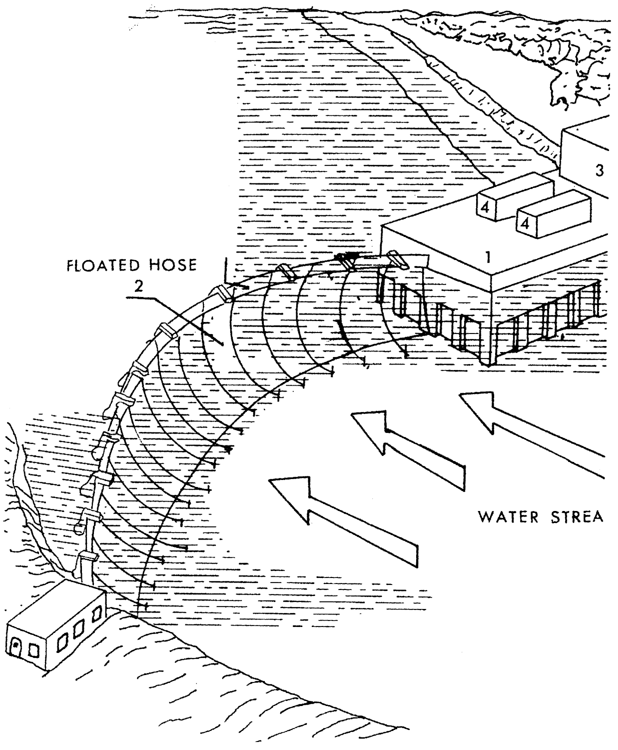


Fig. 9. Gorlov's instant dam (1) powerhouse, (2) floating dam, (3) transmission center.

one is that of a basin filling at flood tide with power produced at ebb tide only. The second uses multiple basins and simple turbines make continuous generation possible. The third approach is that of a single basin but by the use of pump–turbines ebb-and-flood generation is possible, power can be provided on demand and independently of the tide state. Finally with a single basin, simple turbines, a high head-pumped storage arrangement permits continuous, not-tide-connected, maximum efficiency production. The latter is the most expensive scheme to operate.[11]

The Rance River station (Brittany, France) has a retaining basin, a barrage or dam and sluices. Twenty-four bulb type turbines are placed in the dam[12] (Figs. 14–17). Plant turbines can be of the *bulb* or *Straflo* rim-type and even other designs have been tested (Fig. 18). A large head was originally required for a plant to properly function but

[11]Wickert, G., Tidal power. *Water Power*, 1956, 8, 6, 22l–225; *ibid.*, 8, 7, 259–263; Wilson, E.M., Energy from the tides. *Science Journal*, 1965, 1, 5, 50–56.

[12]The Rance and Russian plants use bulb turbines, the Canadians installed Straflo types. *Cf.* Berns[h]tein, L.B., Kislogubsk: a small station generating great expectations. *Water Power*, 1974, 26, 5, 172–177; Charlier, R.H., *Tidal Energy*. New York, Van Nostrand-Rheinhold, 1982, pp. 114–119; De Lory, R.P., Prototype tidal power plant achieves 99% availability. *Sulzer Techn. Rev.*, 1989, 1, 3–8; *ibid.*, The Annapolis tidal generating station. *3rd International Symposium or Wave, Tidal, OTEC and small scale hydro* energy, 1986, III, 125–132; Douma, A. & Stewart, G.D., Annapolis Straflo turbine will demonstrate Bay of Fundy tidal power concept. *Modern Power Systems,* 1981, 1, 53–57; Gibrat, R., L'usine marémotrice de la Rance. *Rev. Franç. de l'Energie*, 1965 *(Num. d'avril)* [in French: The Rance tidal power station].

technological advances permit to use low-head turbines nowadays. Both ebb and flood currents can generate electricity, an achievement that was at the time heralded as a remarkable achievement, but whose extra cost is unjustified according to current thinking of some engineers.[13]

The 9–14 m range tides can produce close to 550,000 kW (Fig. 19). The station is linked to France's national electricity grid. It opened up a rather impoverished Brittany region and allowed it to pull itself up into the 20th century, provided needed power to France as well, and the four-lane highway built on top of the barrage has shorten travel between the two banks of the Rance by several hours. (Fig. 16b). The site, as mentioned previously, is one where several tide mills had functioned for centuries. Its construction tolled the demise of the last tide mills on the Rance. Designed in 1959, the electricity station went into operation 7 years later. Construction cost $100 million (approximately €81.5 million).

The French station is close to celebrating its half-century anniversary. It has performed well, caused minor environmental impacts, lifted an entire region out of an enduring slumber, delivered needed extra power to distant areas. Many lessons have been learned covering both construction and operation. True, the stations built since 1966 have been experimental and/or pilot plants; a major deterrent has been the capital-intensive aspect of such undertakings and the resulting high cost of the delivered kilowatt. However, the cost reducing approaches have lowered the price of power production, further reduced when taking into consideration the life cycle of the plant.

3.2. Other anniversaries

Other birthdays are to be or even have been celebrated. Skipping plants which have functioned before World War I, in Massachusetts and Germany, if we are to give credence to some Chinese claims, a tidal power station was built and put in service in 1959. That would make it 47 years old. We are certain that within 2 years the Russian plant near Murmansk will reach 40 and the Nova Scotia facility has celebrated recently its 30th anniversary.[14]

[13]André, H., Ten years of experience at the "La Rance" tidal power plant. *Ocean Manag.,* 1978, 4, 2–4, 165–178; Banal, M. and Bichon, A., Tidal energy in France—The Rance River tidal power station—Some results after 15 years of operation. *J. Inst. Energy,* 1982, 55, 423, 86–91; Barreau, M., 30th anniversary of the Rance tidal power station: *La Houille Blanche-Rev. Int. de l'Eau* 1997, 52, 3, 13; Bonnefille, R. & Thielheim, K.O. Tidal power stations. 1982 in *Primary energy. Present status and future perspectives*, Heidelberg, Springer Verlag, pp. 319–334; Booda, L.L., River Rance tidal-power plant nears 20 years in operation. *Sea Techn.* 1985, 26, 9, 22; Charlier, R.H., French power from the English channel. *Habitat,* 1970, XIII, 4, 32–33; Charlier, R.H., Comments to "Power from the tides" by C. Lebarbier. *Nav. Eng. J.*, 1975, 87, 3, 58–59; Charlier, R.H., Re-invention or aggiornamento? Tidal power at 30 years. *Ren. Sust. Energy Rev.*1997, 1, 4, 271–289; Cotillon, J., La Rance: six years of operating a tidal power plant in France. *Water Power*, 1974, 26, 10, 314–322; Wilson, E.: Energy from the sea – Tidal power. *Underwater J. & Infor. Bull.* 1973, 5, 4, 175–186; Hillairet, F., Vingt ans après. La Rance. Une expérience marémotrice. *La Houille Blanche-Rev. Intern. de l'Eau,* 1984, 8, 571–582 [in French: Twenty years later. The Rance. A tidal power experience]; Hillairet P. & Weisrock, G., Concrete benefits from operational tidal power station. *International Symposium on Wave, Tidal, OTEC and small scale hydro energy*[Brighton, UK], 1986, III, paper nbr 13, 165–177; Lebarbier, C.H., Power from tides: the Rance tidal power station. *Nav. Eng. J.,* 1975, 83, 2, 57–7l; *ibid.,* Power from the tides. Discussion. *Nav. Eng. J.,* 1975, 87, 3, 52–56; Retiere, C., Bonnot-Courtois, C., LeMao, F. & Desroy, N., Ecological status of the Rance River Basin after 30 years of operation of a tidal power plant. *La Houille Blanche. Rev. Int. de l'Eau,* 1997, 52, 3, 106–107.

[14]See fn 6, 12 and 13.

Fig. 10. Space to insert bulb turbine.

Tidal power stations, such as the Rance, can provide valuable co-generation but the other existing stations are all very modest[15] (Fig. 16). If proponents of tidal stations have shied away from gigantic schemes, such as the Chausey Islands Project[16] for instance, it has not stopped engineers to dream of huge schemes, some proposing to construct a granite barrage across the English Channel. Closer to the present is even a major scheme put recently on track in Korea, where different locations have been repeatedly under consideration.

No less than 21 sites had been under consideration, the oldest one being the Bay of Arcachon (1902) but which would have perhaps wrought havoc for the flourishing

[15] Charlier, R.H., Co-generation from the tides. A review. *Ren. Sustain. Energy Rev.* 2004, 7, 3, 183–213.

[16] Ministère de l'Industrie et de la Recherche [France], L'usine marémotrice des Chausey. In *La production d'Électricité d'origine hydraulique. Rapport de la Commission de la production hydraulique et marémotrice:* Paris, La Documentation Française [Dossiers de l'Énergie 1976, 9, IV, 41–49]. [in French: Ministry of Industry and Research of France. The tidal power station of the Chausey Islands. In *The production of electricity of hydraulic origin.* Report of the Commission of hydraulic and tide generated energy]; see also R. Bonnefille *et al.* fn 13.

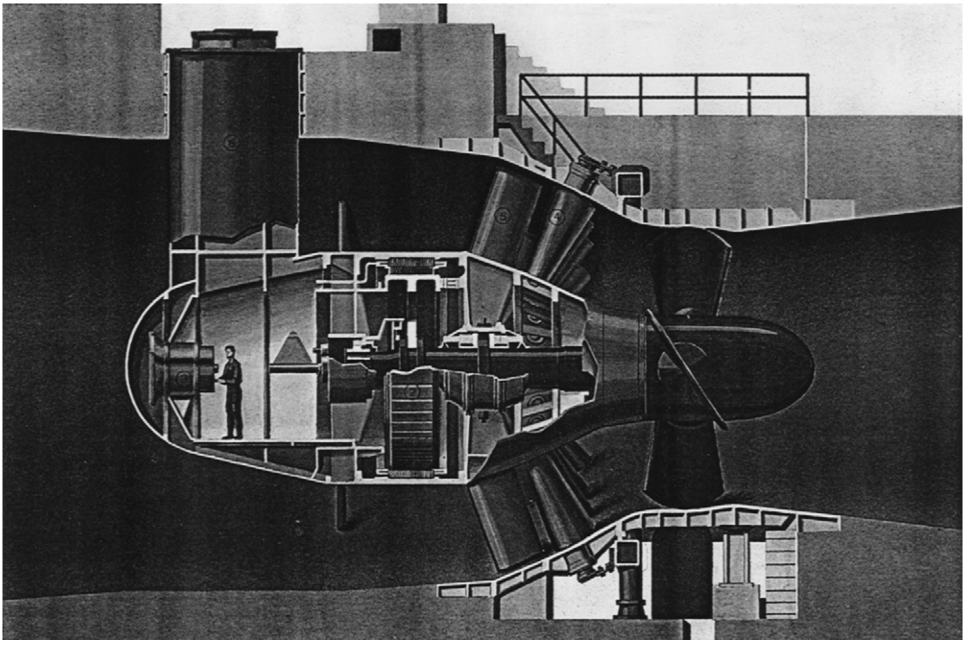


Fig. 11. Schematic (cut) of the Rance TPP type bulb turbine.

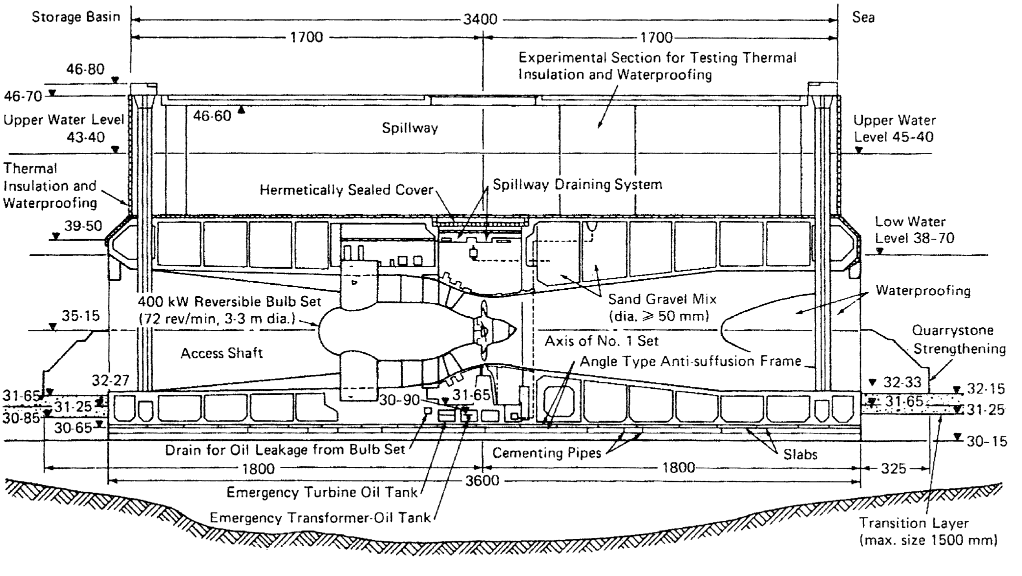


Fig. 12. Cross-section through the pre-fabricated caisson powerhouse and reversible bulb set of the Kislaya scheme.

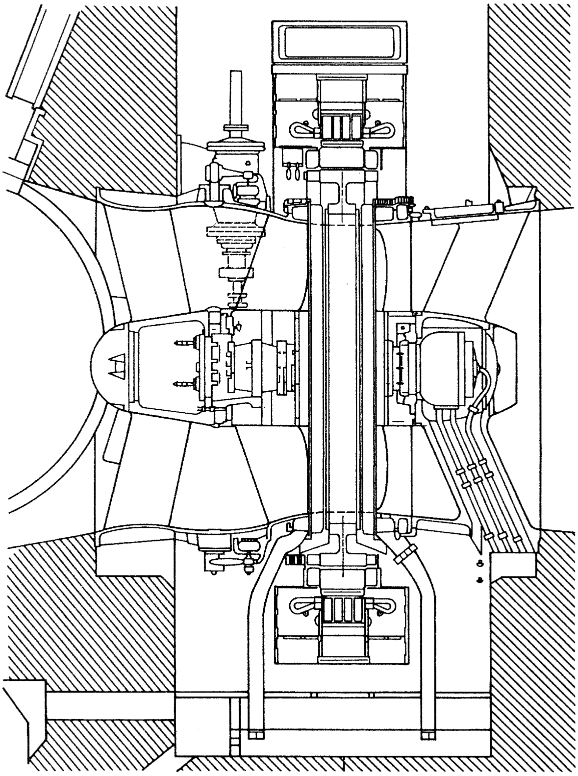


Fig. 13. Cross-section of a typical rim-type generator, the Straflo.

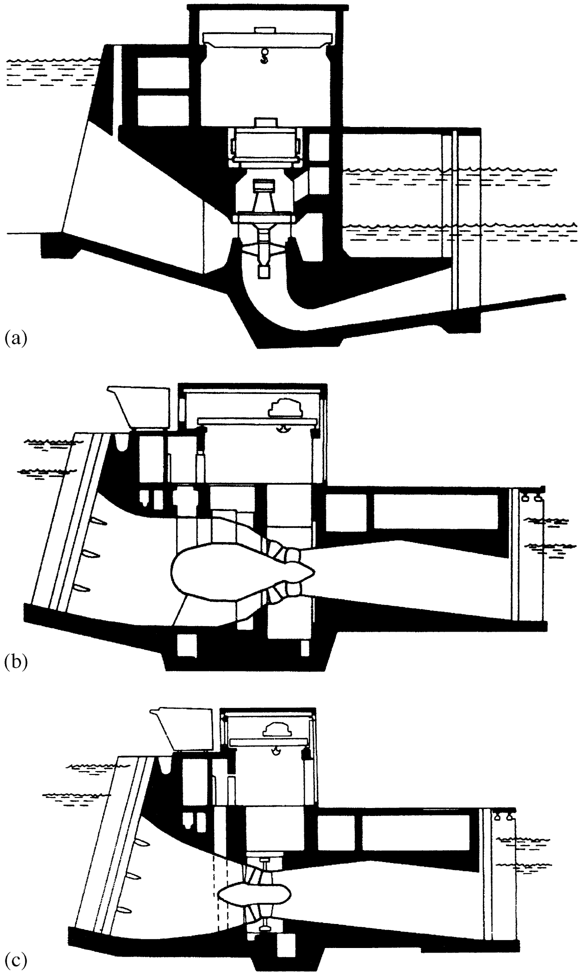
oyster-producing industry. All the early sites were on the Channel, the Dover Straits and the Atlantic. Strangely, up to the very last moment a larger plant had been favored near the Mont St Michel on the border of Normandy, location of a splendid abbey, and a major tourist attraction. The latter may have played a role in the ultimate choice.

3.3. The anatomy of the plant

Besides wiping off the map the local tide mills, construction of the plant required removal of 1,500,000 m^3 of water and the drying up of some 75 hectares of the estuary. As later, though smaller, plants took a different building approach, e.g., avoiding the use of cofferdams, such major civil works are not necessary any longer.

The plant was built in the deepest part of the river. It is a hollow concrete dyke, a tunnel with up- and down-stream linings reinforced by buttresses placed 13.30 m apart. The total width is 53 m with a length of 390 m. The foundations are 10 m below sea level and the top protrudes at 15 m above it. The sas is 13 m wide and 65 m long. The lock gates are vertical shaft sector gates.

Of the 24 bulb groups, sets of twice four groups debit each on a transformer. The transformers are linked by 225 kV oil-filled cables to a substation located on land at about



(a)

(b)

(c)

Fig. 14. Comparison of low head hydropower machines: (a) vertical turbine-generator configuration, (b) horizontal bulb turbine-generator, (c) Straflo turbine/generation arrangment.

300 m from the plant's western end. Three lines transmit power to Paris, and in Brittany to Aube, Rennes, Landerneau and Brest.

The bulb resembles a small submarine and contains an alternator and a Kaplan turbine (Figs. 11,12,14,17,19). Placed in a horizontal hydraulic duct and entirely surrounded by water, the set functions as a turbine and as a pump. The 5 m diameter alternator is directly coupled to the turbine. The 5.35 m diameter turbine is a Kaplan wheel with four mobile blades and vanes; it has a 10,000 W power and rotates at 94 per minute.

In the direct basin to sea sense the group furnishes 10 MW for drops of 11 m and 3.2 MW for drops of 3 m. In sea to basin direction it produces 10 and 2 MW, respectively.

The 14 m wide two-lane highway constructed on top of the dam has put a slow moving and often jammed ferry service out of business and shortens the distance between the

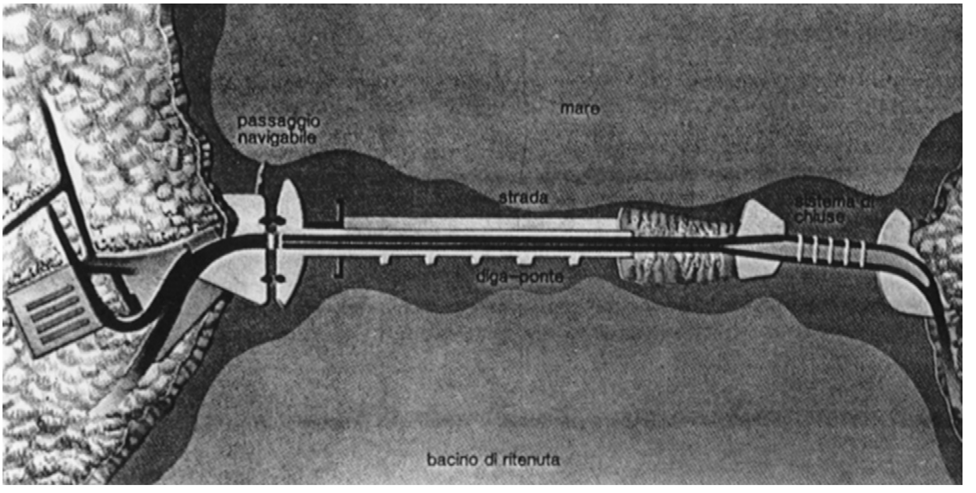


Fig. 15. Aereal view of the Rance TPP, the sea is at top of photo, bottom part is the water retention area.

towns of Dinard and St Malo by 35 km (Fig. 16b). The plant has become a tourist attraction. The fishing industry has remained unaffected and a new community has been developed nearby (Gougeonnais). A fish pathway was provided, a noticeable environmental concern for times when environmental concerns were not front-stage considerations. Only one species of fish, the local *lanson*, [alternative spelling *lanzons*] disappeared. No environmental impact study had however, been made and it took close to 15 years before a report was made that concluded on negligible environmental consequences.

Barnier wrote 40 years ago "Apart from being a magnificent technical achievement in itself, the Rance power station is a symbol of innovation in electricity production which offers the great advantage, as compared to the classic hydro-electric power stations, of functioning with perfect regularity".[17]

4. The Rance: first and last of its kind?

While Electricité de France[18] has remained convinced of the wisdom and worthiness of the Rance plant, it has shelved plans for large stations at the Mont St Michel, the Chausey Islands and the Minquiers. Australia, Argentina, Great Britain are not talking about tidal power plants. Although Great Britain is funding research and trials. And yet so many advances have been realized. Construction of modules on land, then floated into place has been achieved. Dispensing with the onerous cofferdams is an accepted construction approach. Required large heads (tidal amplitude) have been spectacularly reduced. New turbines have been designed. Small plants seem to answer urgent needs of distant regions. Fears for fisheries and tourism have been allayed. Advantages for ostreiculture have been recorded. The benefits of some modes of operation placed in doubt: are ebb and flood

[17]Barnier, L., Power from the tide. *Geographical Magazine,* 1968, 50, 1118–1125.
[18]French Government electricity authority. The "State" company is being privatized in 2006.

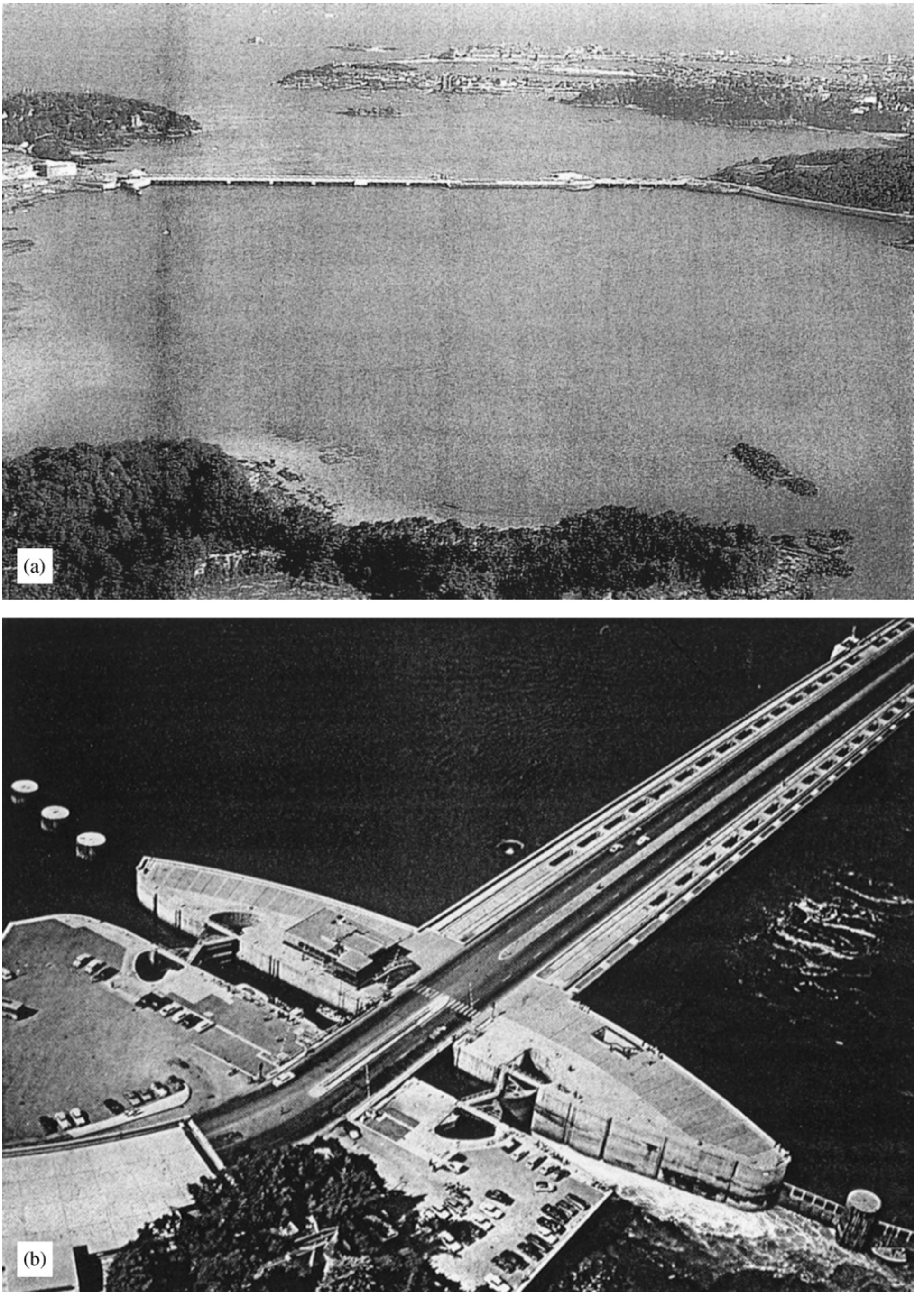


Fig. 16. Views of the Rance TPP barrage showing (a) estuary (b) the four-lane roadway built on top.

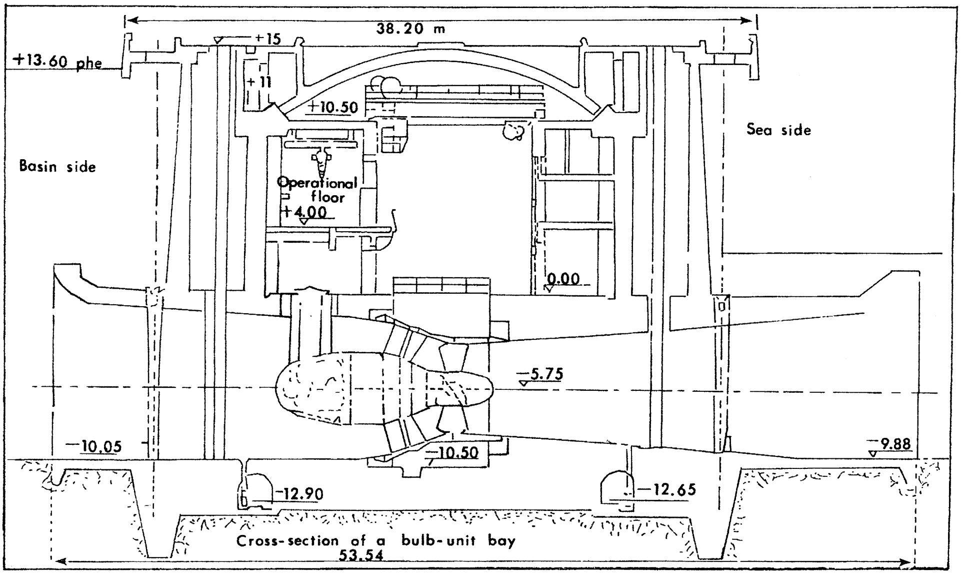


Fig. 17. Cross-section of a bulb-unit bay.

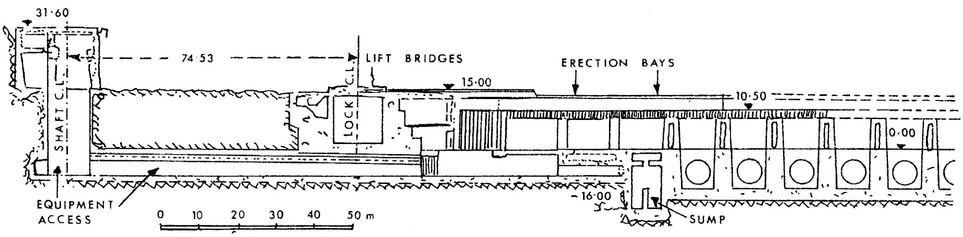


Fig. 18. Cross-cut showing access shaft, lift bridges and erection bays location.

generation, and pumping worth the extra costs? Progress is steadily made with schemes that will allow re-timing by various storage systems.

Tide mills, tidal and tidal current plants' virtues include not to use up irreplaceable stores of energy, not to send into the atmosphere huge—intolerable—amounts of carbon dioxide and other gases, not to contribute to the climate change and the warming up of the atmosphere, and simultaneously to be a continuously available source of energy.

Though some species lost their habitat during the construction period and did not return afterwards, something that will be avoided by dispensing with cofferdams, no 'major' biological-ecosystems modifications occurred. Other species colonized the abandoned space. Yet, some environmental changes did take place in the Rance estuary area: sandbanks disappeared, the beach of St Servan, badly damaged during construction, only partially regained its former lustre; high-speed currents have developed near sluices and powerhouse in whose vicinity sudden surges occur. The tidal range has been reduced and maxima dropped from 13.5 to 12.8 m while minima increased roughly proportionally. In fact the green tides [algae proliferation and subsequent strandings] that have been

plaguing the French coasts of the Atlantic are a source of far larger economic concern than the implant of the tidal power plant.[19]

The economic impact is viewed as favorable with regional industrialization, increase of tourism and substantial growth of the communities involved (St Malo, Dinard).

Forty years went by and except for the far smaller Kislogubsk (Russia) plant (Fig. 7), no other large-size tidal power plant using bulb turbines has been built. Will there be none ever constructed again? Other ocean energy converting stations seem to have gained favor, waves and winds, and tidal currents. And yet, Korea seems to have opted for a barrage-type plant which is to generate 240,000 MW. At this writing few details have been released even though construction start is announced for 2006. The plant would incorporate areas of Lake Sihwa [alternative spelling: Siwa] and be built entirely by Korean companies (Fig. 20).

Tidal power can indeed also be harnessed by diverting part of a flow and using the to and from movement of the tide-induced current, pretty much like a run-of-the-river approach.[20,21] The flow of the tidal current is diverted in part into a channel where it turns a wheel; some tide mills operated by tapping the energy of the tidal current.[22] Tidal current power is currently more frequently mentioned than tidal barrages.[23,24,25,26] Such power plants need no cofferdams for construction nor barrage, sluices and retaining basin. Though electricity production is more modest, it is far less expensive. Everyone does not agree, however, that tidal currents constitute a big saving from barrage schemes.[27]

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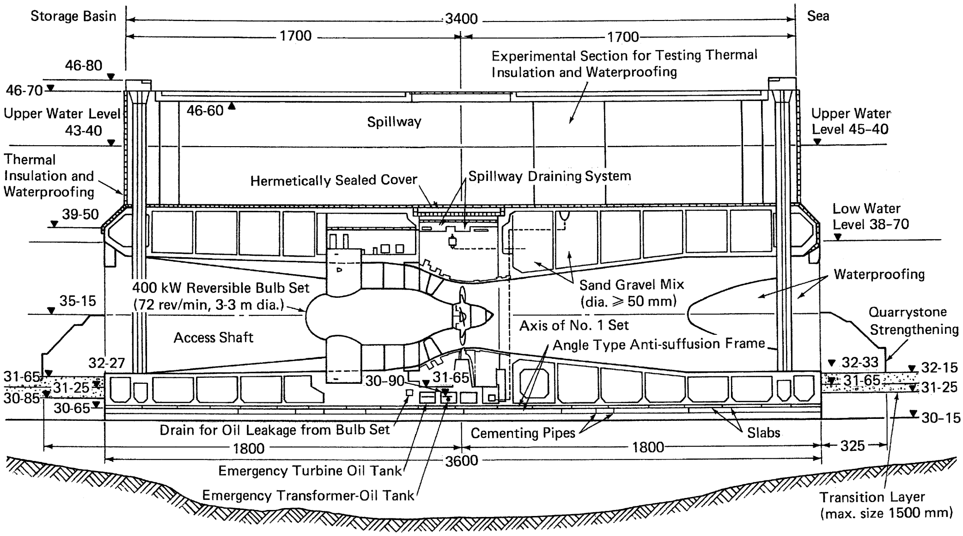

Fig. 19. The bulb unit turbine installed in TPPs in France and Russia.

Tidal currents vary with depth. In deeper water density stratification may lead to varied velocity profiles. The stratification may result from salinity, temperature or to the amount and nature of sediments transported by the current. Velocity may also be influenced at different depths due to Coriolis effects or even to bottom topography. Tidal flow being unsteady, the direction and magnitude of tidal currents at depth may, due to bottom friction, lag behind the surface layers' current.

The tidal current resource is gravitational bound, thus highly predictable, but it is, however, not in phase with the solar day. One hundred and six locations in Europe if put "in service" would provide 48 TWh/yr exploitable.[28]

4.1. The past and the future

Some tide mills took advantage of the ebb and/or flood current. Some such mills were even 'dual-powered'. Tidal current mills operated on one of two systems: they were equipped with a single wheel that rotated with the current between two pontoons, or the mill consisted in a single pontoon with a wheel affixed to each side, similar to the approach with paddle-wheelers.

Tidal current river energy can be tapped both in the sea environment and in tidal rivers and streams. Its potential is large.

A technology assessment conducted by New York University on behalf of the State of New York[29] and dealing principally with the tapping of the tidal current in the East River

[28]European Union-Joule Project, *Exploitation of tidal marine currents* (JOU2-CT94-0355/EC-DG XII): Brussels, European Commission. 1996.

[29]See fn 30 and 31.

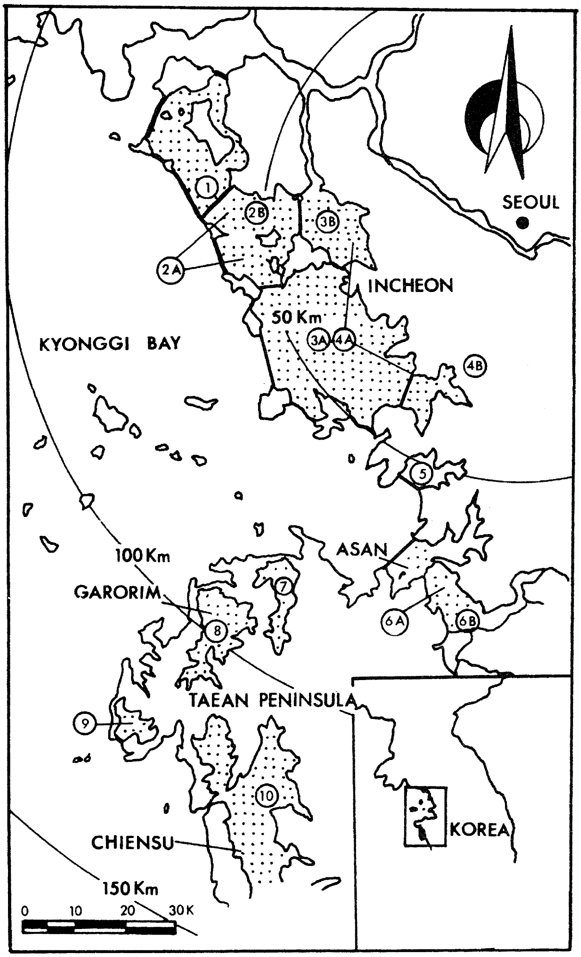

Fig. 20. Map of possible and probable sites for TPPs in the Republic of South Korea.

in New York City, yielded information on a number of devices which could be usable and on the advantages of axial-flow propeller machines.[30,31]

A prototype was installed in the East River's semi-diurnal Eastern Channel in 1985.

[30]Miller, G., Corren, D. and Franceschi, J., *Kinetic hydro energy conversion systems study for the New York State resource-Phase I, Final Report*: New York, Power Authority of NY State 1982[contract NYO-82-33/NYU/DAS 82-108]; Miller, G., Corren, D., Franceschi, J. and Armstrong, P., *idem-Phase II, Final Report:* New York, Port. Author. 1983[contract *idem*]; Miller, G., Corren, D. and Armstrong, P., *idem-Phase II and Phase III, Model Testing:* New York, State Energy Research & Development Authority & Consolidated Edison Company of New York, Inc. 1984 [NYU/DAS 84-127]; Miller, G. *et al., idem*: *Waterpower '85-International Conference on Hydropower* (*Las Vegas NV*) 1984–1985, 12 pp.; Anonymous, Underwater windmill: *The Energy Daily* Dec. 20, 1984, p. 2; Anonymous, East River tides to run electrical generator: *New York Times* Apr. 14, 1985 p. 52; Anonymous, New York plans for hydroplant using kinetic conversion approach: *Bur. Nat. Aff. Energy Rep.* Jan. 3, 1985, p. 9.

[31]Calculated in 1980-$.

Table 2
Relative duration, expressed in %, of the various operation modes at the La Rance tidal power plant

MODE	%
Direct generation	56.00
Reverse generation	11.70
Direct pumping	14.70
Reverse pumping	1.40
Spilling (direct and reverse)	16.20
Total	100

Table 3
Actors on the research and development scene♣

Australia
Tidal Energy Pty Limited (tidal energy), Queensland, Australia

Belgium
ESHA, European Small Hydropower Association, Brussels
Eufores, European Forum for Renewable Energy Sources, Brussels
HAECON, Harbour Engineering Consultants, Drongen-Ghent

Brazil
Leony Polatti-Tidal Energy

Canada
Blue Energy Canada (turbines for current, tidal, OWC energy), Alberta

China
China New Energy (tidal energy, ocean current, wave energy, thermal energy, salinity gradient energy)

France
Comité de Liaison des Energies Renouvelables, Montreuil sur mer
Electricité de France (Tidal barrage), La Rance River, St Malo, Britanny
IFREMER, Institut Français de Recherches et d'Exploitation de la Mer, Paris
Sogreah (Société Grenobloise d'Applications Hydrauliques), Grenoble

Germany
Deutsche Wasserstoff Verband, Berlin
Institut fuer Energie und Umwelt, Leipzig

Greece
DAEDALUS Informatics (turbines for current, tidal, OWC energy), Athens
CRES, Center for Renewable Energy Sources, Pikermi, Athens

Korea
Korea Water Resources Corporation (KOWACO) (tidal energy), Sihwa
Daewood Construction Company (tidal plant construction) Seoul

Netherlands [The]
Neptune Systems (offshore, nearshore tidal current and wave energy)
De Kleine Aarde, (consultancy), Boxtel

Norway
Hammerfest Stroem AS (tidal energy), Finmark

Russia
Kislaya Bay Tidal Power Station, Kisgalobskaia, Murmansk

Table 3 (*continued*)

Sweden
Turab turbine & Regulator Services (turbines) Nässjö
Switzerland
Escher-Wyss AG, (tidal plant turbines) Zürich
United Kingdom
City [of London] University, London
Hydroventuri (marine tidal current energy), London
IT Power (marine tidal current energy), Hampshire
Marine Current Turbines, Ltd. (turbines for current, tidal, OWC energy), Hampshire
Robert Gordon University (marine tidal and current energy), Aberdeen, Scotland
School Mechanical Engineering, University of Edinborough (tidal energy), Scotland
Seacore (tidal power), Gweek, Helston, Cornwall
The Engineering Business Limited (nearshore tidal energy)
Thropton Energy Services (tidal energy, power, plants) Thropton, Morpeth, Northumberland
Tidal Electric. Ltd. (near shore tidal energy), West Simsbury, CN
United States of America
ABS Alaskan (turbines for current, tidal, OWC energy), Fairbanks, AK
GCK Technology, Inc. (Gorlov Helical Turbines), San Antonio, TX
Harza Inc. (tidal power projects) Chicago, IL
HydroVenturi (tidal energy), San Francisco, CA
Rahus Institute, Martinez CA
Kinetic Energy Systems (tidal current energy), Ocala, FL
Tidal Electric, Inc. (nearshore tidal energy), West Simsbury, CT and Anchorage, AK
UEK Corporation (turbines for current, tidal, OWC energy), Annapolis, MD
UNITAR-Small and Alternative Hydropower, United Nations, New York NY
Verdant Power (tidal current energy), East River, New York

♣ Examples of tidal energy developers, installations, consultants, corporate enterprises and research institutions from around the world, listed by country (modified, completed and in part excerpted from Practical Ocean Energy Management Systems, Inc., [acronym POEMS], http://www.poemsinc.org/links.html).

4.2. Discussion

The performance of the Rance River plant has been closely monitored and this provided the opportunity for the publication of assessments at about decadal intervals. Papers by André, Barreau, Hillairet and Lebarbier deserve mention in this regard.[32] The 40 years of operation have proven the viability of tidal power plants.

The Electricité de France, the French Government-owned utility responsible for the plant expressed, after 25 years of operation that its specially designed bulb-type turbines performed well. It emphasized, at the time, that the station is not operated to extract maximum energy but, as any commercial plant, to yield the maximum profit.

Yet, by then there had been problems to solve and failures to mend. Thirty years ago some pinnings were shaken lose, but were repaired successfully. The frequent start-ups wore on the generators, which necessitated repairs. They were provided in the late 1980s with a reinforced coreframe fastener system; this allowed henceforth synchronous starting. Starting is no longer from standstill, and from then on a sequence was followed wherein

[32] See fn 13.

pumping is preceded by operation as a sea to basin sluice. A unit starts at a 30–40% of its rated speed, before synchronization with the grid, and stress on the generator is reduced.

Of the six operation modes, generation by basin overemptying has been but rarely used since the early 1980s. At that time the company still firmly believed, however, of the value of direct pumping (Tables 2 and 3).

True, plant construction remains capital incentive, but longevity is not an advantage to be passed over lightly. A conventional plant would have shown fatigue. Were a large tidal power plant to be constructed elsewhere several new approaches would be implemented.

Acknowledgments

The author wishes to thank Dr. Patrick Vanouplines for the substantial help provided in the literature search by scrutinizing documents and information available at the Central Library of the Vrije Universiteit Brussel ([Flemish]Free University of Brussels, Belgium) of which he is the Director. Appreciation is also expressed to the Institute for Development, Research, and Education in the Coastal Zone for support.

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